Understanding Apex Predator and Pelagic Fish Habitat Utilization in the California Current System by Integrating Animal Tracking with in situ Oceanographic Observations

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LONG-TERM GOALS

The team includes researchers from the University of California Santa Cruz (UCSC), National Marine Fisheries Service (NMFS), and Stanford's Hopkins Marine Station. Oceanographers from the Environmental Research Division (ERD) at NMFS will provide expertise in remote sensing of the Northeast Pacific oceanography. The integration and analysis of the diverse datasets requires the development of new software which is being developed by the NMFS,UCSC, and Stanford as well as researchers from Sea Mammal Research Unit (SMRU) in Scotland. We plan to map the oceanic habitats used by top predators in the California Current System (CCS). This will be done by examining both top down and bottom up processes, and predicting how climate variability impacts the distribution and utilization of oceanic habitats within the CCS. We are also developing methods that are required to integrate animal collected data into existing oceanographic databases.

OBJECTIVES

This study will develop a dynamic, ecosystem-based approach to map and understand habitat utilization by top predators in the CCS. Specifically, our objectives are:

(1) To map critical habitat of predators in the California Current System;

(2) To link the movement patterns of these predators to physical and biological ocean features, in order to:
   a. determine how ocean dynamics act to aggregate diverse organisms;
   b. define the stability and community structure around biological hot spots;
   c. define the persistence of hot spots in space and time;
   d. examine the relationships among different species in the context of habitat utilization;

e. identify the influence of top down and bottom up processes and their influence on dynamics of hot spots;

(3) To map habitat distribution of commercially-viable and threatened fish stocks in the CCS, based on predator distribution and behavior from tracking data;

(4) To quantify the seasonal and interannual variability of mesoscale ocean features (potential hot spots) in the CCS, from remotely sensed and in situ data;

(5) To contribute a significant quantity of high-resolution in situ oceanographic data from animal tags to coastal and global ocean observing programs;

(6) To provide critical advice to fisheries managers on the distribution of commercially-viable fish stocks in relation to oceanographic variability;

(7) To develop and test models that allow for the prediction of animal abundance and distribution based on the physical environment.

APPROACH

Oceanographic data will be obtained from both satellite imagery and the electronic tags which record environmental variables such as temperature, depth, light and salinity. Physical data obtained by tagged animals will permit comparison to features that are spatially and temporally concurrent with the animals' foraging behavior. For example, temperature and salinity data collected by the tags will place the animals' behavior in the context of distinct water masses. Large-scale habitat usage will be modeled based on individual animal utilization. Habitat preference is indicated when an animal uses an area more than would be expected based on relative availability of habitat. Our approach to define habitat usage will be to start by modeling the relative accessibility of habitat mechanistically based on distance from a capture site, speed of movement, and the observed distribution of trip durations. These estimates will then be used as variables within a Generalized Additive Model (GAM) approach to relate the environmental variables that define habitats and spatial utilization by tagged animals.

One of the critical requirements in ecosystem-based resource management is learning how to define zones of high biological activity, or "biological hot spots". How best to characterize these "hot spots", whether determination is based on how animals use the habitat (behavioral changes), or how to quantify their temporal variability, stability and long-term viability, remains unknown. Regardless, the first step is to identify where they occur. The Tagging Of Pacific Pelagics (TOPP) research program, which is composed of the member groups listed above, will provide new data on spatial and temporal characteristics of hot spots in the CCS as well as new methods to identify them using both remotely sensed oceanographic information and data obtained from the tagged animals.

WORK COMPLETED

Advances in electronic tag technology have provided TOPP with the tools necessary to describe the movements and behaviors of marine vertebrates and large squid in the North Pacific and to identify hotspots and migratory corridors. The tag-bearing animals continue to serve as autonomous ocean profilers providing key oceanographic data to the growing global databases. The vertical and horizontal movements of tagged marine vertebrates have provided the sampling of more remote, traditionally undersampled oceanic areas, as well as providing unprecedented temporal and spatial coverage of the North Pacific. To date, over 2,500 tags have been deployed and several million ocean observations have been documented. Efforts to database the entire TOPP data set are on-going and new collaborations with JPL-NASA for data assimilation into ocean general circulation models have been established.

RESULTS

Elephant Seals: In order to address colony bias, we have initiated tracking from one of the most northern colonies Año Nuevo, California to one of the most southerly San Benitos Islands, Baja, Mexico. These two colonies span the entire known breeding range of northern elephant seals – a distance of 1,200 km (or ~750 miles). There are distinct differences in the movement patterns of elephant seals between these colonies. We are deploying Fastloc GPS tags on elephant seals and sea lions that were developed under our previous NOPP award (Fig. 1). These tags are currently producing up to 57 extremely accurate seal locations per day, which equates to a geoposition after every second dive. The increased frequency of geoposition recording will yield a much finer temporal and spatial

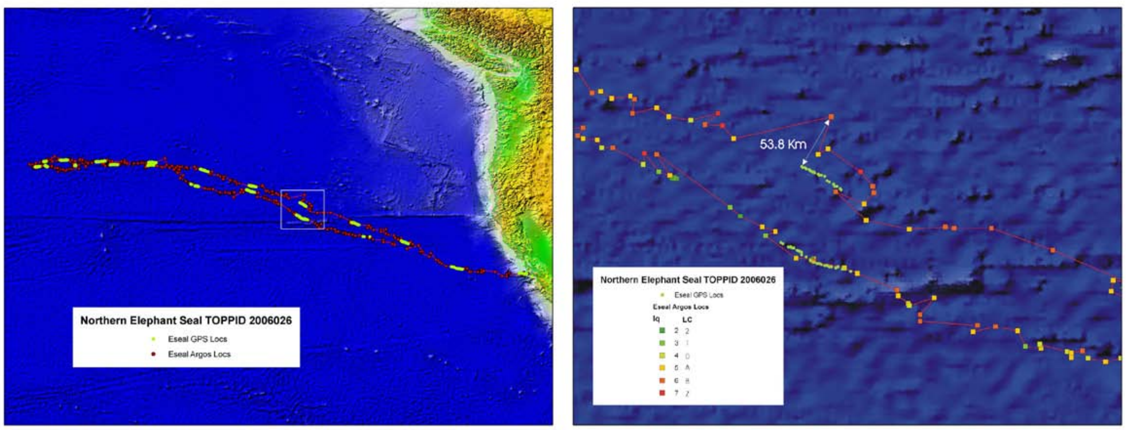


Fig 1 elephant seal tracks using Fastloc GPS

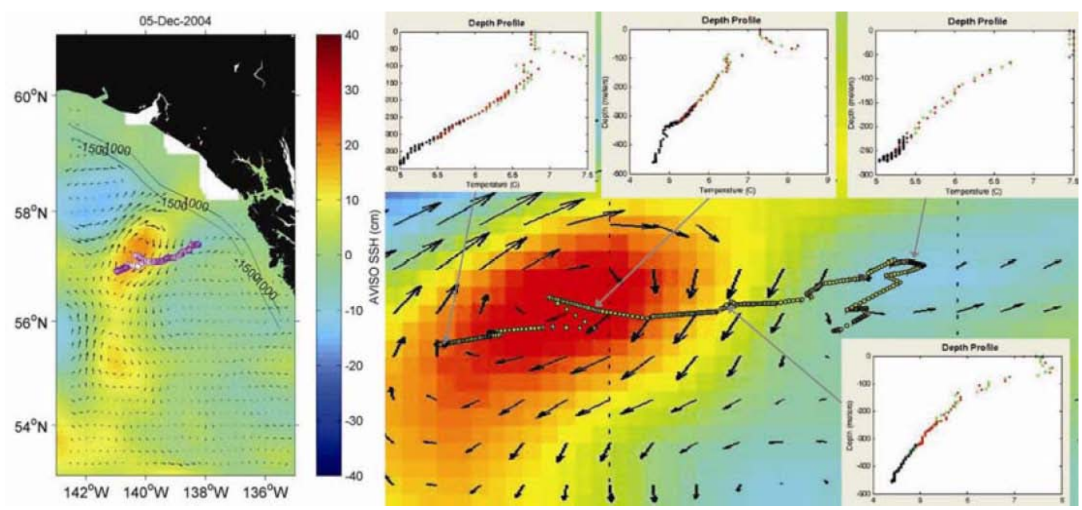
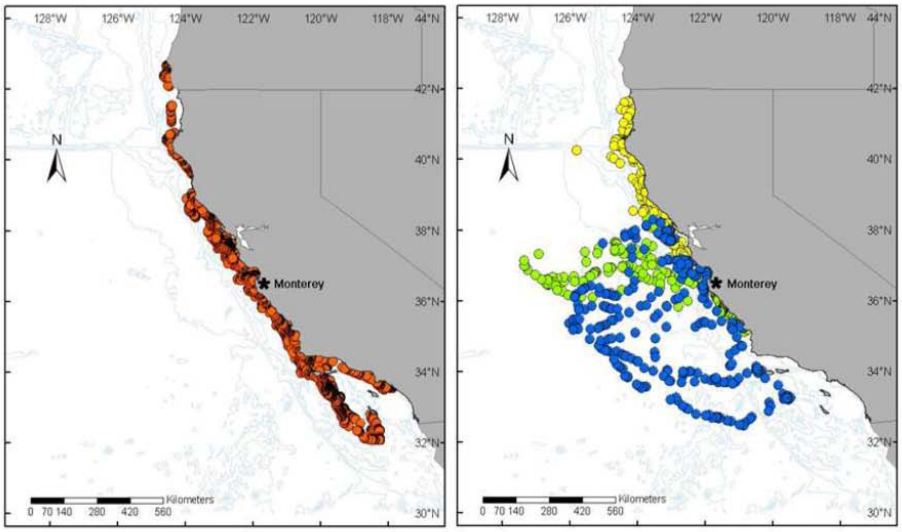


Fig 2. Elephant track showing temperature profile as the animal moves through the eddy.

resolution of foraging behavior than was previously possible. Figure 2 shows the physical environmental data obtained by an elephant seal as it foraging in an eddy in the Gulf of Alaska.



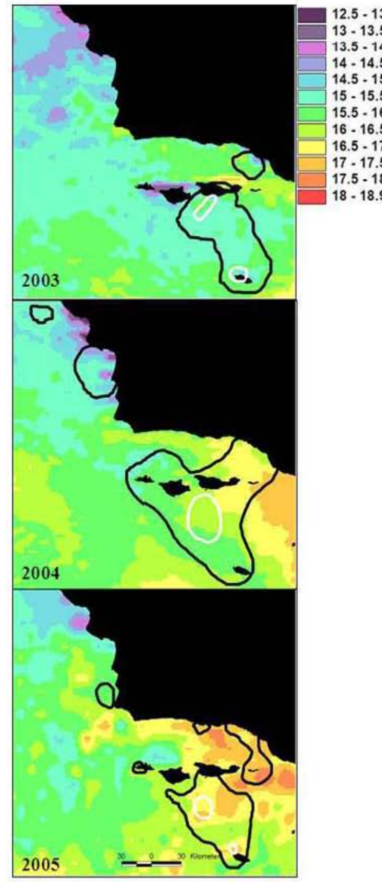


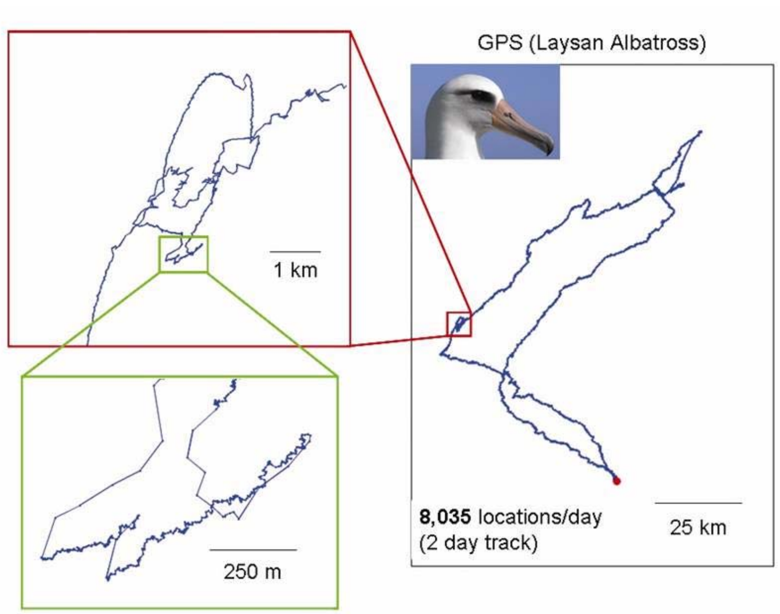
Fig. 3 above left shows tracks of male sea lions during 2003-4 Compared to above right of animals during 2004-5.

Fig. 3 vertical right shows change in foraging range of female sea Lions over 2003, 2004, and 2005.

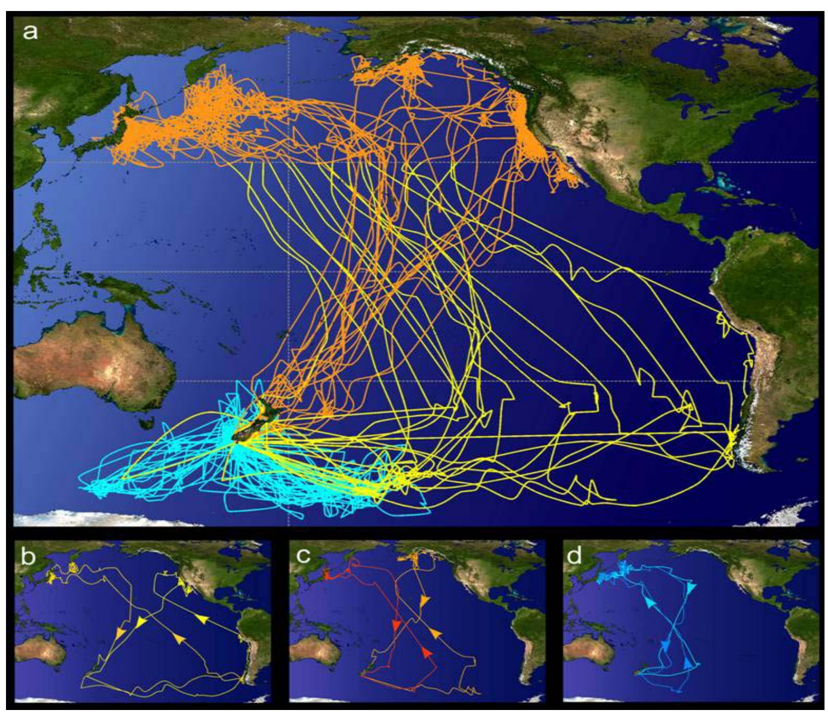
California Sea Lions: We documented changes in the habitat utilization of male and female California sea lions over a three year period. In winter 2003-04, adult male sea lions remained close to the California coast feeding exclusively over the continental, while during 2004-05 season male sea lions traveled 300-500 km offshore (Fig. 3). Similarly female sea lions changed there foraging behavior and patterns in response to differences in sea surface temperature over showed the greatest change in at-sea behavior when sea surface temperature was warmest (2004 & 2005) (Fig 3). During spring and summer of 2005 normal upwelling favorable winds were suppressed due to the blockage of the jet stream resulting in the latest onset of upwelling on record. These conditions resulted in the most spatially extensive and persistent sea surface temperature and primary productivity anomalies since the 1997-98 El Niño.

Cetaceans: In August 2005, 15 blue and 7 humpback whales (3 off Oregon) were tagged with satellite transmitters. The majority of blue whales traveled within 100-200 km of the California coast, although individuals ranged offshore up to 2,000 km. In contrast, humpback whales remained closer to the coast. The blue whales moved at higher speeds and also appeared to be more transient with movements up and down the coast than the humpbacks. Two whales ventured as far south as Costa Rica. Another whale that has been tracked for more than 16 months repeated much of the previous year's pattern during the fall and winter, with multiple offshore routes during the southward migration. In general, blue whales move farther from shore into deeper water than the humpback whales, reflecting the differences in diet between the two species. Blue whales feed on euphausids, whereas the humpback whales have a more generalized diet, which includes small schooling fish found predominately near shore.

North Pacific Albatrosses:
Albatrosses have been studied at two locations: 1) Tern Island, Northwest Hawaiian Islands, and 2) Guadalupe Island, Mexico. The studies at both colonies provide an interesting contrast between one population that feeds primarily in the California Current and the other that feeds predominantly in pelagic waters of the North Pacific Current. In December 2005, 4 Laysan albatrosses were equipped with archival GPS tags that recorded highly accurate locations every 10 seconds, providing an astounding 20,000 locations per day over a three day period (Fig. 4 right).



Shearwaters: In fall 2005, we obtained the first tag recoveries from migrating sooty shearwaters equipped with archival geolocation tags during the breeding period in January 2005 at two breeding colonies in New Zealand. Upon completion of breeding in New Zealand, each bird migrated to one of three destinations in the North Pacific: 1) western Pacific, 2) Alaska, and 3) Coastal California and over-wintering zones in the northern hemisphere. Shearwaters traveled more than 60,000 km roundtrip, which is one of the longest animal migrations yet recorded. The diving behavior of the birds in both hemispheres reveals a strong association with cool (4-14°C water; range of mean for southern and northern hemispheres, respectively) high seasonal primary productivity. Diving depths also averaged 12-14 m, although depths as deep as 68.2 m were recorded. This strategy of breeding in New Zealand during the austral summer followed by a migration to the northern hemisphere during the boreal summer allows sooty shearwaters to enjoy an endless summer while exploiting oceanic resources on a global scale (Shaffer et al. 2006).



Pacific Tunas (Bluefin, Yellowfin and Albacore): The objectives are to understand how these three closely related tunas use the California Current and to identify regions of high residency along the North American Coast and North Pacific ecosystem. TOPP has amassed an impressive dataset on bluefin, yellowfin and albacore tuna including approximately 55,000 days of data on tuna movements in the north Pacific. With are comparing the seasonal movements and vertical habitat use of the yellowfin, bluefin and albacore tuna. Outside of the transpacific migrations of bluefin, the bluefin and yellowfin remain relatively close to the coast with the bluefin occupying cooler waters at higher latitudes than the yellowfin. While yellowfin and bluefin show seasonal north and south movements the albacore move to the east and west. Interestingly, all three species overlap off California and the Baja Peninsula in the late summer (Fig. 6). An examination of dive patterns indicates that while all three species show spend greater than 97% of their time in the top 200 m there are some differences among species. Maximum dive depths recorded so far are greatest in the yellowfin, up to 1000m, followed by bluefin, and then albacore. The daytime diving behavior is most prevalent in albacore that appear to be feeding in the deep scattering layer (DSL), consistently making repetitive dives into the DSL during the day.

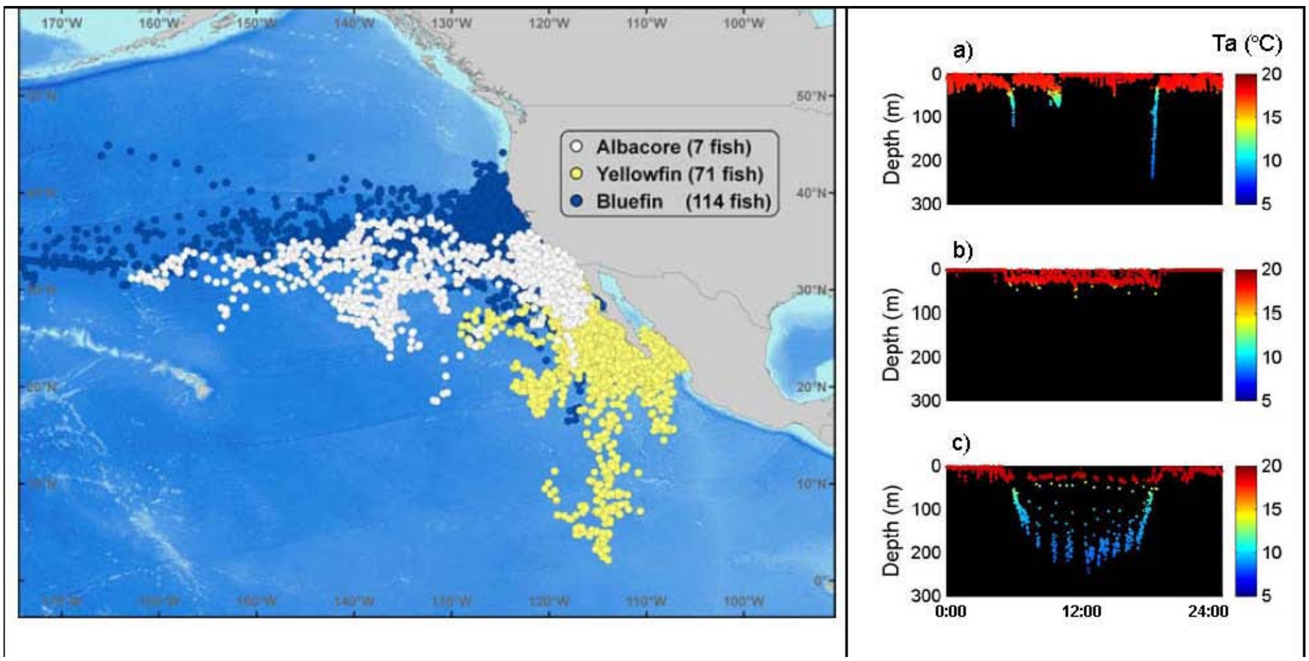


Fig. 6. A) Geolocation estimated for albacore (white), yellowfin (yellow) and bluefin (blue). B) The depth and temperature of bluefin, b) yellowfin and c) albacore for one day during the summer when all species are in the same regions off Northern Baja, Mexico.

Sharks: 5 species of oceanic sharks migrating are being studied because they are important predators, prefer a range of prey items from fish to pinnipeds, and cover diverse habitats. Four species, the white, thresher, mako and salmon sharks are all endothermic to varying degrees and capable of elevating body temperature above water temperature. The fifth shark species is the blue shark a more temperate species that is an ectothermic shark. Over the last year, total of (68) pop-up satellite archival (PAT) tags were deployed on blue, mako, salmon and white sharks. The fast responding thermistor now allows for more accurate measurement of the water column profile and sea surface temperature (SST), which will improve SST-based latitude estimates. Over 5,000 temperature and depth profiles have been gathered in the North Pacific from shark data sets. The salmon sharks provide the largest and most reliable platform for SPOT tagging and to date, have carried spots for as long as 2.7 years while still transmitting accurate data. This has provided unprecedented tracks, allowing for repeat migrations of individuals from Prince William Sound, Alaska to the tropics over consecutive years. The SPOT tags applied to blue and mako sharks provided tracks of two to 1.9 year durations. Blue sharks have been on average smaller when tagged and the tags have provided significant data in the first few months but have been less reliable over the long run. Over the past year 30 PAT tags have been deployed on 29 adult white sharks. The mid pacific area, half way between California and Hawaii, an area increasingly being identified as potential hot spot region for white sharks. To date we have tagged a total of 69 white sharks, 59 of these were adults tagged in Northern California.

IMPACT/APPLICATIONS

Our ability to identify oceanic hotspots used by marine predators will have significant implications for fisheries management and conservation. For example, areas that are deemed “sensitive” or critical to the proliferation of a given species could be protected or managed. However, because the oceans are so dynamic, it is important to identify key features or consistent phenomena (e.g. coastal upwelling or other physical forcing) that affect ocean productivity and the aggregation of predators and prey.

TRANSITIONS

The GPS tag design developed by WildTrack Ltd (Leeds England) with support from our previous NOPP award is now under production by the Sea Mammal Research Unit and has been licensed to Wildlife Computers Inc (Redmond WA) and Sirtrack Ltd New Zealand. These tags are now commerically available (Figure 7).

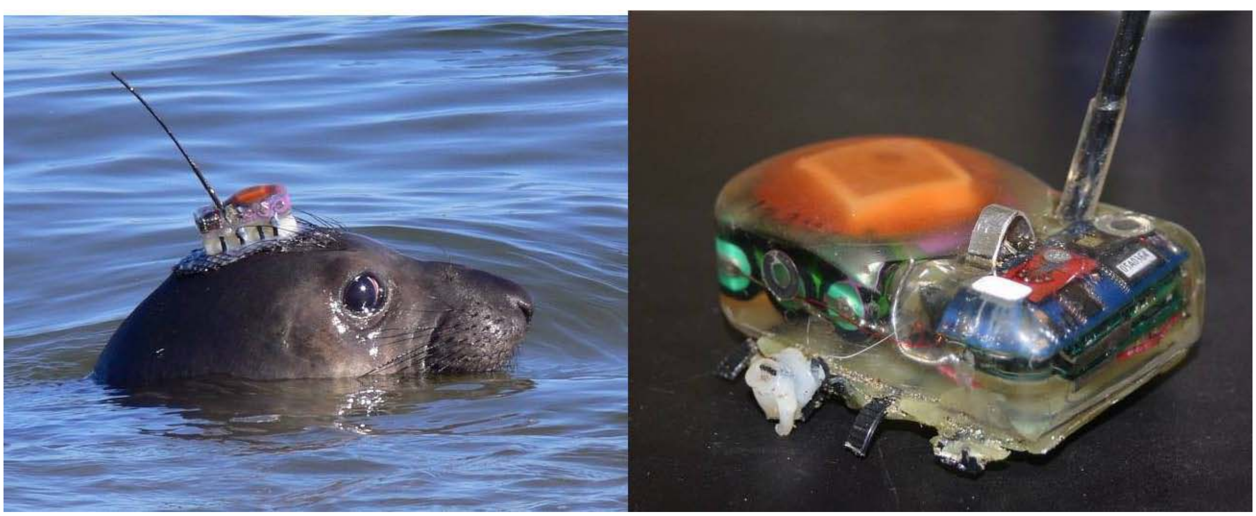


Figure 7. Left a 2 year old northern elephant seal at sea wearing the newly developed Wildlife Computer GPS. Right. Close up image of the GPS tag after recovery.

Science Education and Communication

The Pis sponsored by this NOPP award held an international workshop on Biological Hot Spots in Pacific Grove, CA, December 7-8th, 2005. The goal of the workshop was to bring together experts in biologging science, physical and biological oceanography, and remote sensing in order to come to a better understanding of how to define, identify, and classify biological hot spots. The workshop attracted more than 70 participants from eight nations. Plenary sessions were held on the integration of oceanographic and tag data, spatial mapping applications, and methods of modeling animal movement. A half-day was spent in four breakout groups, which had more in depth discussions on these topics.

Highlights of the breakout groups were summarized in a final plenary session. The workshop represented a unique collaboration between three CoML projects: TOPP, the Ocean Biogeographic Information System (OBIS) SEAMAP program, and the Future of Marine Animal Populations (FMAP) program. The workshop was highly interdisciplinary, which led to the vigorous exchange of ideas on the nature of biological hot spots and the analytical methods that can be applied to their study.

The NOPP award has directly supported a NMFS research associate and scientific programmer, 4 post doctoral researchers and 2 graduate students. The results of this research are communicated to the public on the TOPP web page, www.toppcensus.org.

RELATED PROJECTS

This project relies on data collected by the Tagging of Pacific Pelagics program (TOPP) which is a pilot project of the Census of Marine Life (http://www.toppcensus.org). All the electronic tagging data for the project will be obtained from animals deployed as a part of the TOPP program. TOPP is pioneering the application of biologging science to study pelagic habitat use by marine vertebrates and large squid in the North Pacific.

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